Uncertainty as a Function of Time for Subcritical Experiment Parameters

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General Overview

- When designing critical or subcritical experiments, it is desirable:
  - to have an estimate of the measurement uncertainties prior to performing an experiment
  - to have the smallest measurement uncertainties possible given measurement time constraint
- Having well-designed experiments with small uncertainties helps improve nuclear data and therefore has direct impacts on criticality safety.
- This work shows how the uncertainties in various measurement parameters vary as a function of counting time and provides an approach to estimate measured uncertainties and guide in optimizing the available counting time.

General Overview

- Everything in this work uses the measurement approach and uncertainty analysis presented in the BeRP/Ni benchmark.
- Detailed in LA-UR-16-20375 and ICNC 2015
- General overview of approach:
  - Cf-252 measurements used to determine detector efficiency.
    - Primary method uses Cf-252 source certificate.
    - Appendix includes use of singles and doubles.
  - Singles and doubles count rates of BeRP measurement used with efficiency to determine leakage multiplication.

Limited analytical results

- One can set the uncertainty (δ) in singles (R_1) and doubles (R_2) count rates to 0 (expected at infinite count time) and determine the minimum:
  - Uncertainty in detector efficiency (δε)
  - Uncertainty in leakage multiplication (δM_L)
  - Uncertainty in BeRP spontaneous fission rate (δF_S)

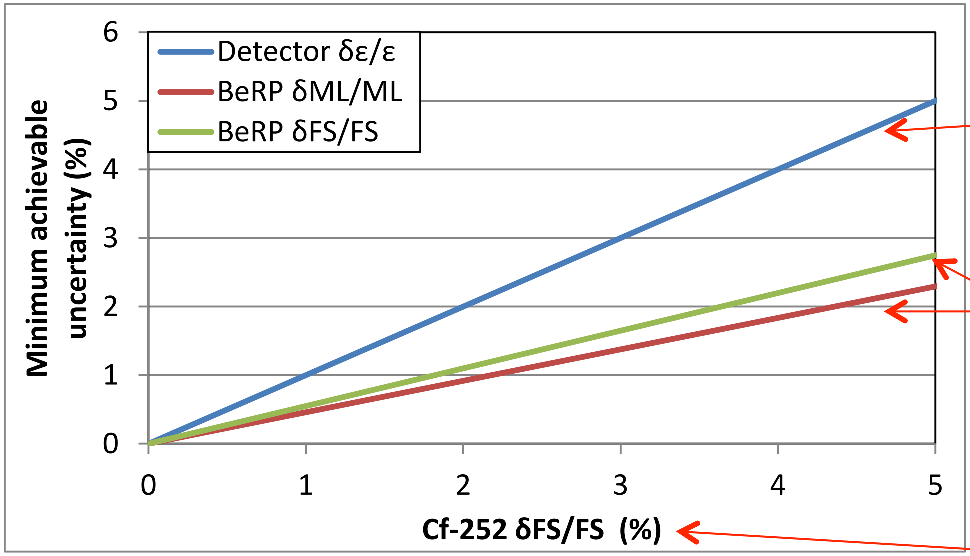
Cf-252 measurement

$$\delta\varepsilon = \varepsilon\sqrt{\frac{\delta R_1(\tau)^2}{R_1(\tau)^2} + \frac{\delta F_S{}^2}{F_S{}^2}}$$

$$\lim_{\delta R_1 \to 0} \delta\varepsilon/\varepsilon = \delta F_S/F_S$$

BeRP measurement

$$\lim_{\delta R_1 \to 0, \delta R_2 \to 0} \delta M_L/M_L = \left|\frac{\partial M_L}{\partial \varepsilon}\delta\varepsilon\right|$$

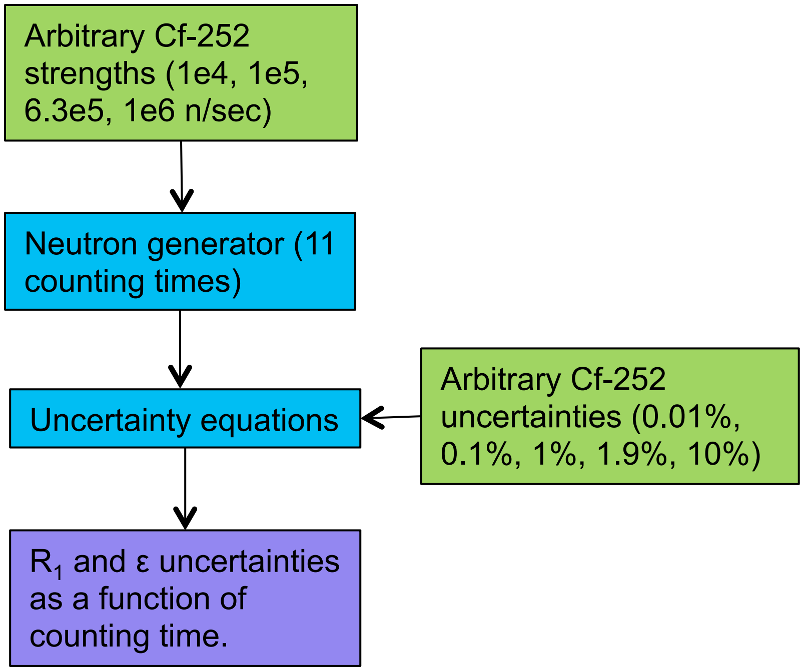


True for ANY system/configuration

Specific to the measured configuration (bare BeRP shown here).

Uncertainty in Cf-252 emission from source certificate.

Data process



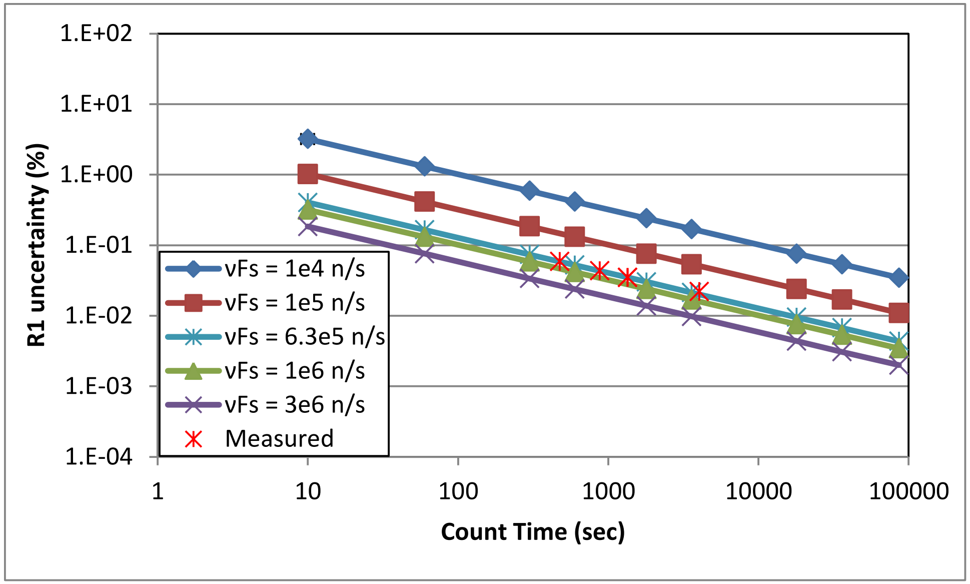
Inputs

Data processing

Outputs

Sum of all counting times: ~8 days.

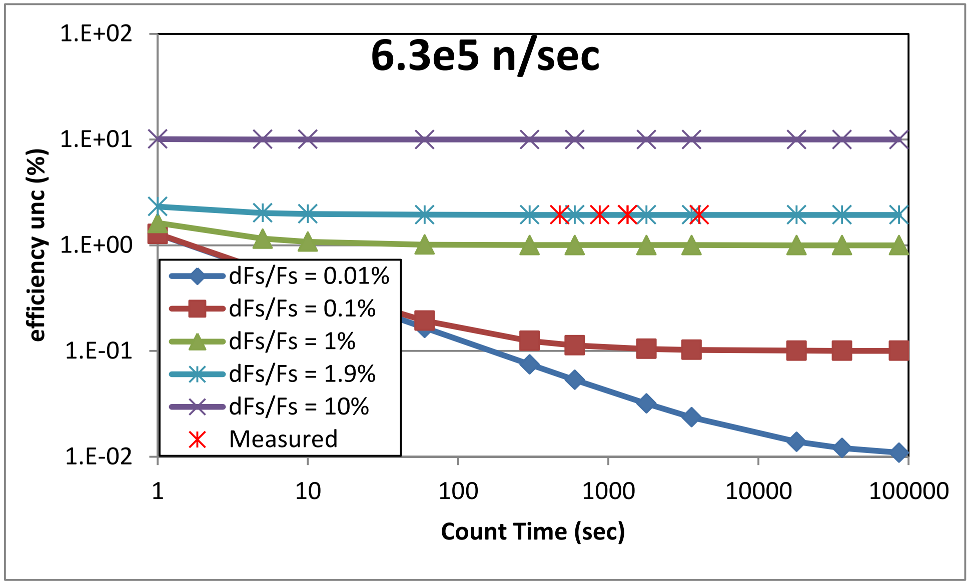
Cf-252: R1 uncertainty



$$\delta R_1(\tau) = \frac{1}{\tau}\sqrt{\frac{2m_2(\tau) + m_1(\tau) - m_1^{\,2}(\tau)}{N-1}}$$

- The uncertainty in singles count rate (δR_1) decreases as a function of the square root of the counting time as expected (count time and N are proportional).
- As the Cf-252 source strength (νF_S) increases, δR_1 is smaller at any given count time as expected.
- These curves are independent of $\delta F_S/F_S$

Cf-252: Efficiency uncertainty



Cf-252 measurement

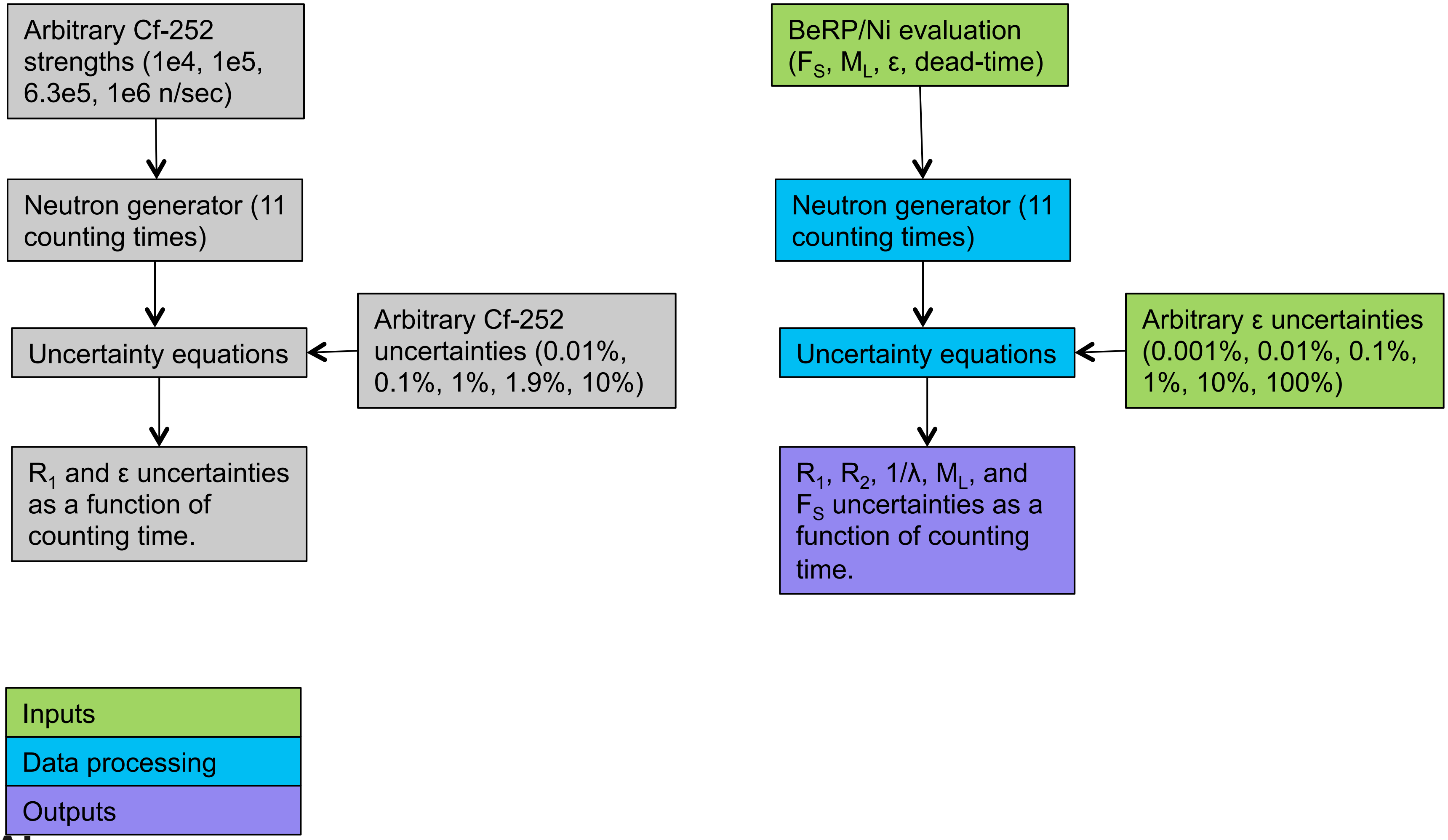
$$\delta\varepsilon = \varepsilon\sqrt{\frac{\delta R_1(\tau)^2}{R_1(\tau)^2} + \frac{\delta F_S^{\ 2}}{F_S^{\ 2}}}$$

$$\lim_{\delta R_1 \to 0} \delta\varepsilon / \varepsilon = \delta F_S / F_S$$

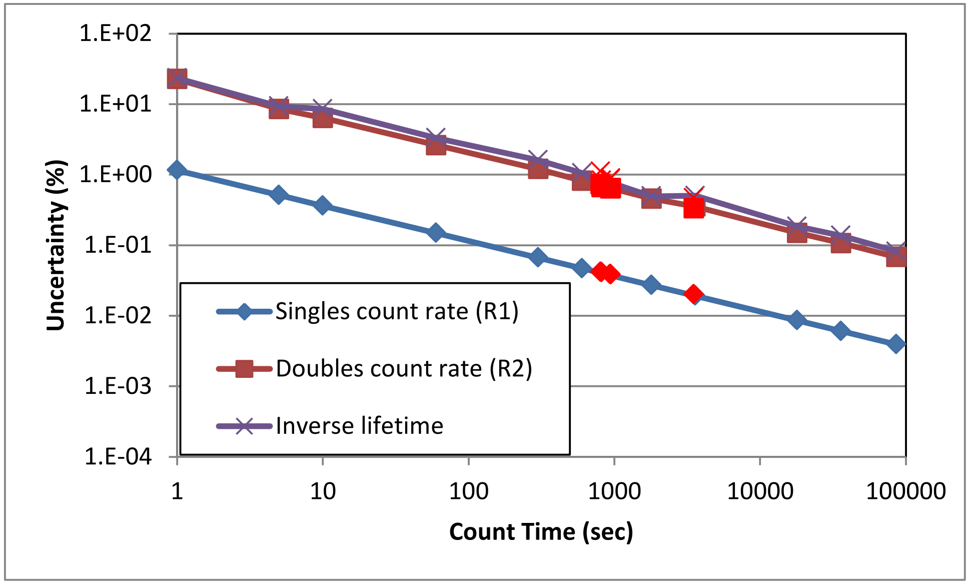
These types of curves were generated for 4 source strengths.

- At short count times, the efficiency uncertainty (δε) has contributions from δR_1 and δF_S. As count time increases, the uncertainty approaches an asymptote equal to the uncertainty in the Cf-252 source emission rate (δF_S).
- As the source strength increases, the time to δR_1 decreases, so the time to reach the asymptote decreases.

Data process



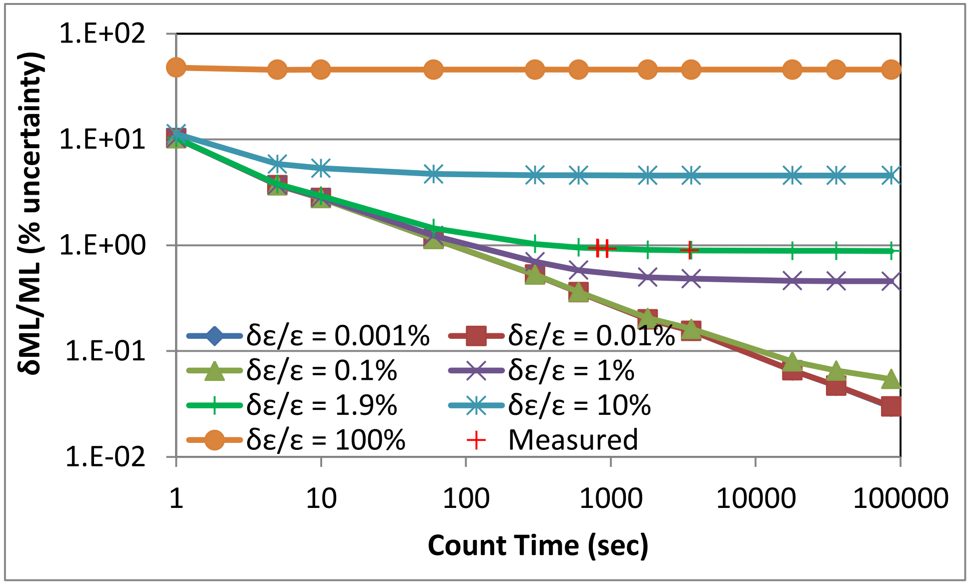
BeRP



$$\delta R_1(\tau) = \frac{1}{\tau}\sqrt{\frac{2m_2(\tau) + m_1(\tau) - m_1^{\,2}(\tau)}{N-1}}$$

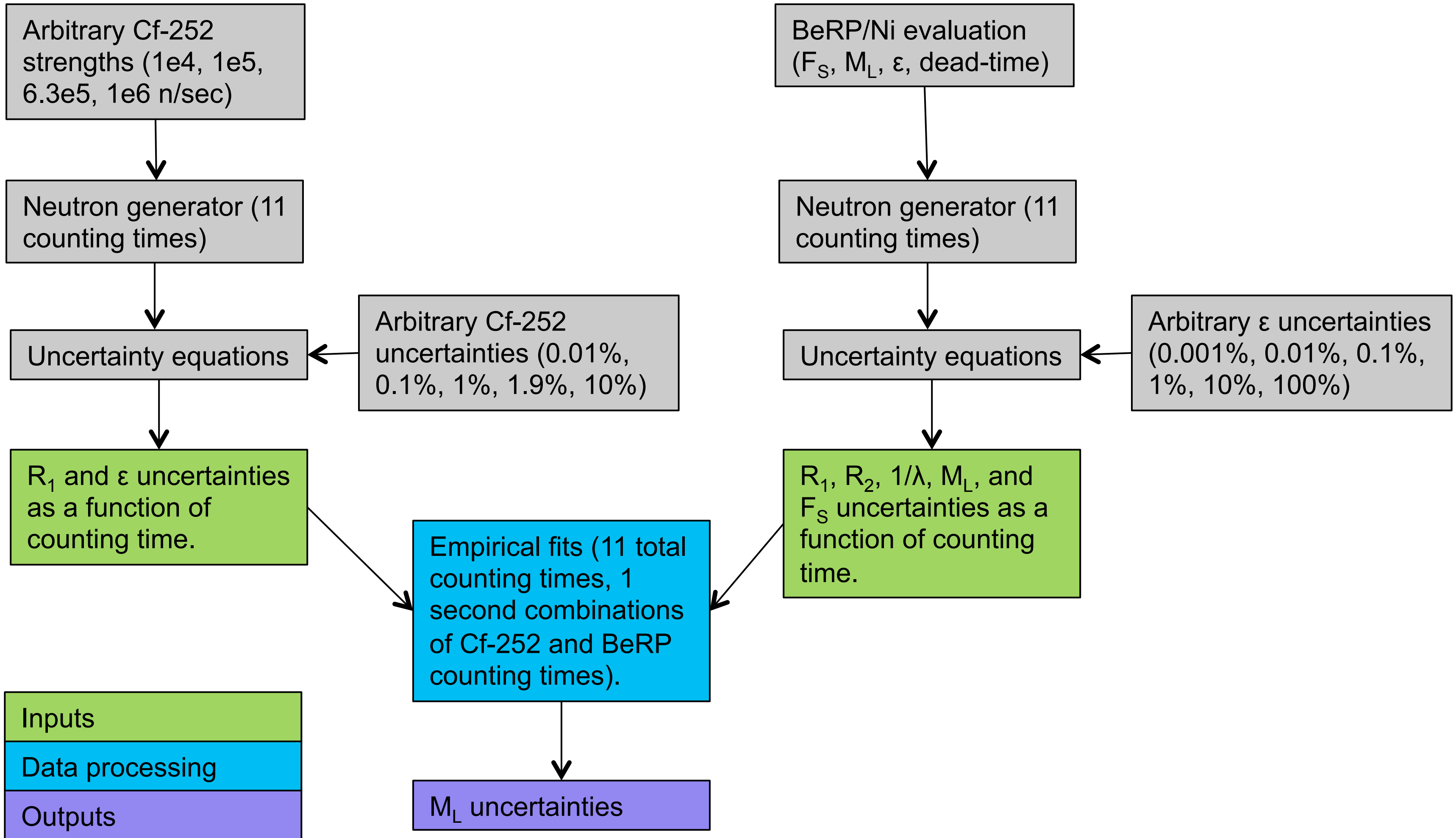
- The uncertainty in singles count rate (δR_1), doubles rate (δR_2), and inverse lifetime (λ) decreases as a function of the square root of the counting time as expected (count time and N are proportional).

BeRP

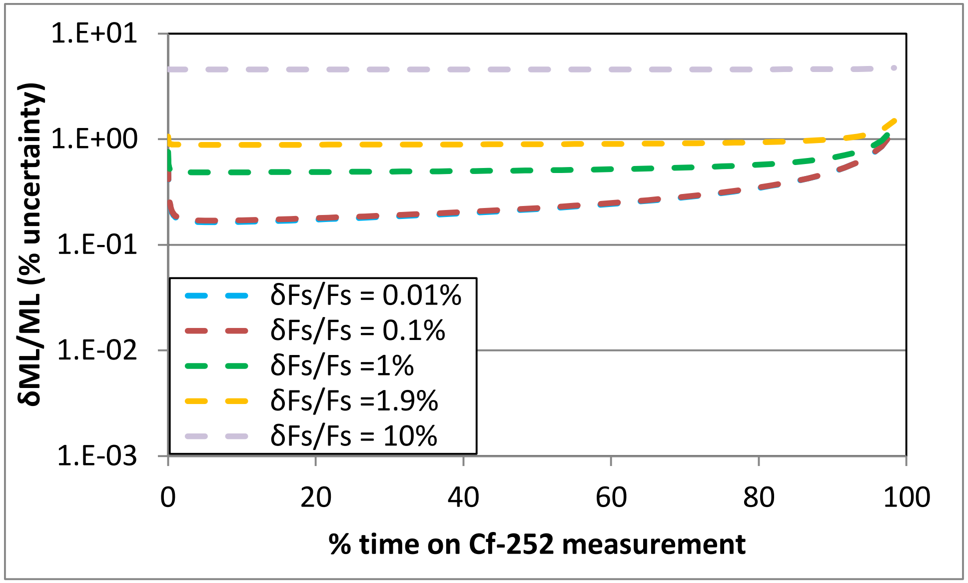


- At short count times, the leakage multiplication uncertainty (δM_L) has contributions from δR_1, δR_2 and $\delta\varepsilon$. As count time increases, the uncertainty approaches an asymptote proportional to the uncertainty in detector efficiency ($\delta\varepsilon$).

Data process



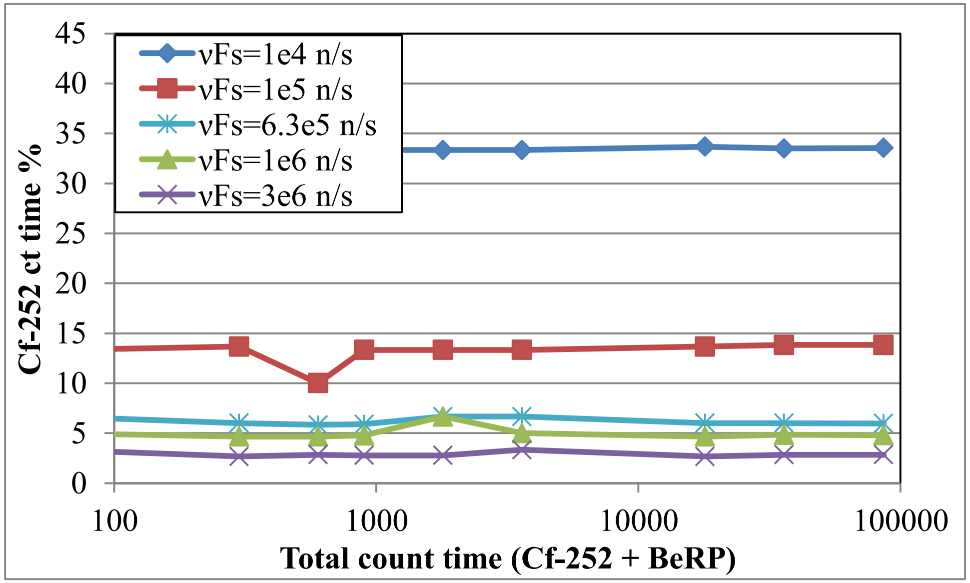
Cf-252 + BeRP: 3600 total count time



These types of curves were generated for 11 different total counting times.

- Assumes that if X% of time is spent measuring the Cf-252, then (100-X)% of time is spent measuring the BeRP.
- While the minimum uncertainty is strongly dependent on the uncertainty of the Cf-252 source strength, the percent time at which the minimum occurs does not.

Cf-252 + BeRP

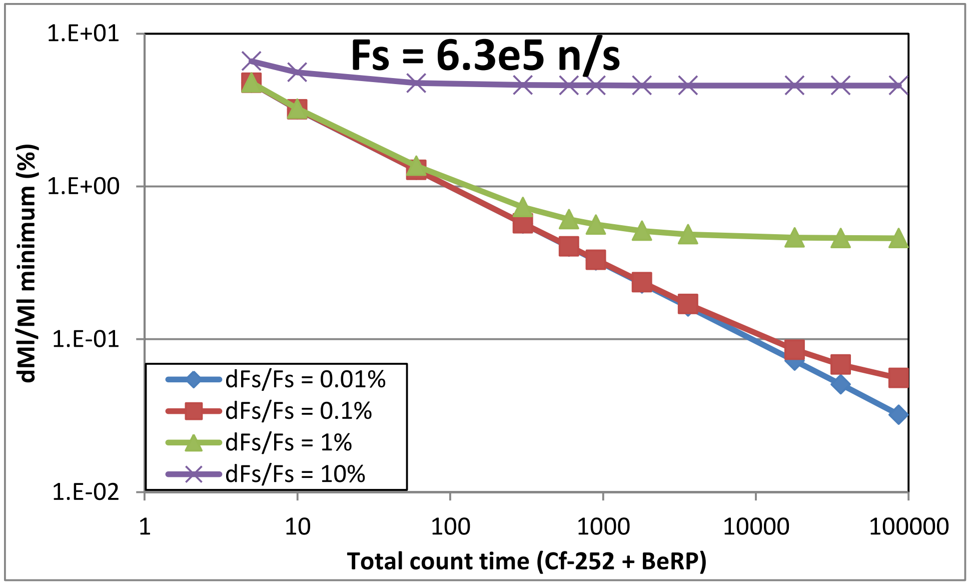


Recall the statement: "Cf-252 measurements used to determine detector efficiency. Primary method uses Cf-252 source certificate. Appendix includes use of singles and doubles."

These curves would be completely different if the second approach was used.

- The % time that should be spent counting the Cf-252 is independent of the source strength uncertainty (δF_S).
  - But dependent on the source strength value.
- The % time that should be spend counting the Cf-252 is mostly independent of the total counting time.

Cf-252 + BeRP



These types of curves were generated for 4 source strengths.

Uses ideal Cf-252 percent measurement time.

- This type of curve is very useful for experiment design.
- It shows the minimum leakage multiplication uncertainty (δM_L) achievable for any given total count time (Cf-252 measurement time plus BeRP measurement time).

Conclusions

- The uncertainty as a function of counting time was investigated.
- This answered three important questions related to subcritical measurement design:
  - How much time one should measure Cf-252 versus the SNM object (bare BeRP used here).
  - An estimate of the minimum possible measurement uncertainties (as a function of Cf-252 source emission uncertainty).
  - An estimate of the minimum possible uncertainty in various parameters as a function of counting time.
- Note that the Cf-252 results were general (several source strengths were investigated) but the SNM results are specific to the bare BeRP ball.
  - One needs to apply this approach to the specific configuration(s) that will be measured.
- With the approach that we have used (Cf-252 measurements with source certificate to determine efficiency) the uncertainty in the source emission is very important.
  - For SCRαP, the new Cf-252 source uncertainty is half of that used in BeRP/Ni (1% vs 1.9%)
  - We are investigating if we can get sources with smaller uncertainties.

Future work

- This approach will be applied to future subcritical experiments.
  - IER-~~111~~422: Subcritical Copper-Reflected α-phase Plutonium (SCRαP) Integral Experiment.
- Can this approach be applied in a more general way for SNM measurements?
  - This should be investigated further.
- We will also consider applying this optimization approach to other subcritical measurement methods.
  - Rossi-α, time interval, other Feynman methods, etc.

Acknowledgements

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